

COEFFICIENT OF FRICTION IN DIFFERENT ROAD CONDITIONS BY VARIOUS CONTROL METHODS - AN OVERALL REVIEW

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ABSTRACT

Modern day automotive technology is advancing at a rapid rate resulting in vehicles with outstanding performance and speed. Therefore, the need of the hour is to reengineer and refine existing automotive systems to better suit the requirement of a modern day vehicles. Vehicles with high speed require an equally efficient traction and braking system. In this present work, we study and compare the performance of vehicles under different road conditions using conventional braking, anti-lock braking system and traction control system, and study the relation of coefficient of friction and wheel slip ratio for different road conditions. In the following project, an experimental setup to imitate tire road interactions is made to collect data of wheel slip and coefficient of friction under conventional braking, Antilock braking system and Traction control system. The obtained data and facts from the experiment is then compared and analysed. The results from the experiments suggest that wheel slip is highest at the peak braking force and although ABS & TCS improve traction and control, it increases the stopping distance of a vehicle proportionally, which can be dangerous in certain scenarios. In conventional braking at 100%, total wheel lock occurs, while in ABS & TCS at 65% slip traction is generally regained. At 65% slip in conventional braking, CoF is 0.69 whereas in ABS, CoF is 0.854 and in TCS, CoF is 0.812.

KEYWORDS: CoF, Conventional Braking Mechanism, Antilock Braking System (ABS) & Traction Control System (TCS)

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1. INTRODUCTION

The introduction of controlling the dynamics of wheel in a vehicle was first done in anti-lock braking system to prevent lockup of wheel in an emergency breaking manoeuvre. However, the idea to control wheel dynamics while braking was broadened to control wheel dynamics and other aspects such as engine torque, fuel supply to provide better traction while accelerating and cornering. Thus, traction control system was developed which included ABS into itself, and provided a 20-30% increase in the performance and control of a vehicle. Traction control technology is paramount to vehicle safety in slippery road conditions. Observing wheel slip is the first step in creating a system that controls in real time or prevents large differences between vehicle and wheel speed

In the following project, performance of wheel under different road conditions such as rough pavement, smooth pavement, gravel, mud and ice is studied using analysis of coefficient of friction and slip ratio as study parameter under different road conditions using conventional braking, Antilock braking system and Traction control system.

An experimental setup is made to imitate the tire road interactions using wheel a roller and a load motor for the purpose of determining the coefficient of friction and wheel slip in different road surfaces. Thereafter, the obtained results are compared with the results from other braking methods.

1.1 Conventional Braking

Conventional braking is a braking method, which usually involves pulling a lever or pressing a pedal connected to levers or linkages to transmit forces to the brake mechanism consisting of shoe and drum or disc and brake pads, thus generating friction between two surfaces to stop a vehicle.

There are three types of conventional braking mechanism

- **Mechanical Brakes**

Utilizes a cable attached to a brake lever and the brake drum pistons to engage brakes. This mechanism was used in vehicles from the 19th century, and is currently used as parking brake mechanism.

- **Hydraulic Brakes**

Utilizes a hydraulic pump and a brake oil reservoir connected to the brake pedal to the create pressure to engage brake pistons. These types of systems can be found in regular four wheelers.

- **Pneumatic Brakes**

Similar to hydraulic, but utilizes air pressure to engage brake pistons. Usually used in heavy industrial and commercial vehicles, as the amount of pressure required to stop such load cannot be achieved using hydraulics.

Although conventional braking has the smallest ideal braking distance, it has a major drawback when the maximum brake pressure is applied, the wheels get locked. These results in wheel slip, which causes the vehicle to skid uncontrollably and the driver to lose steering control.

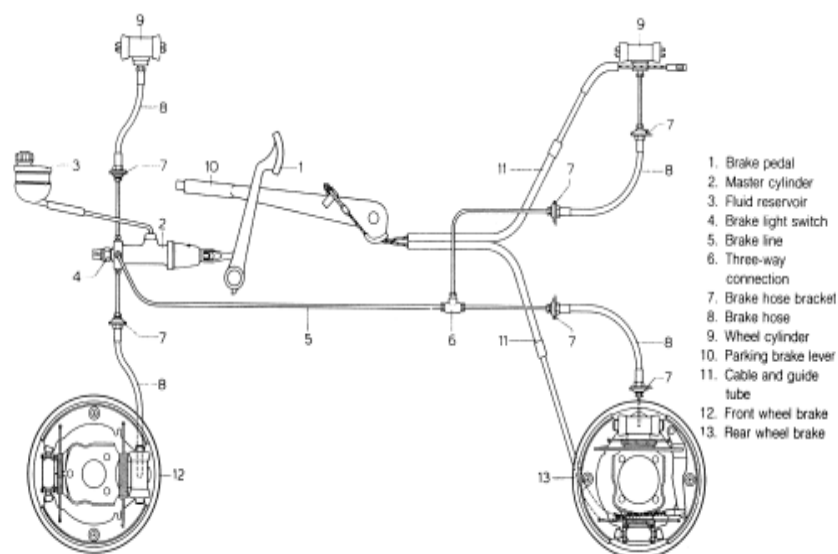


Figure 1.1: Conventional Brakes

1.2 Antilock Braking System

Antilock Braking System (ABS) is a safety feature in most modern day vehicles. It utilizes a combination of threshold braking and cadence braking to prevent locking of wheels and wheel slip, when sudden brakes are applied. Rude models of ABS were introduced as early as 1920, but a patented fully functional ABS was introduced in an automobile by Chrysler in 1971 in its Imperial model.

1.2.1 Components of ABS

Major components of Anti-lock braking system are

- Electronic control unit (ECU)
- Hydraulic control Modulator
- Booster and master cylinder assembly
- Wheel sensor

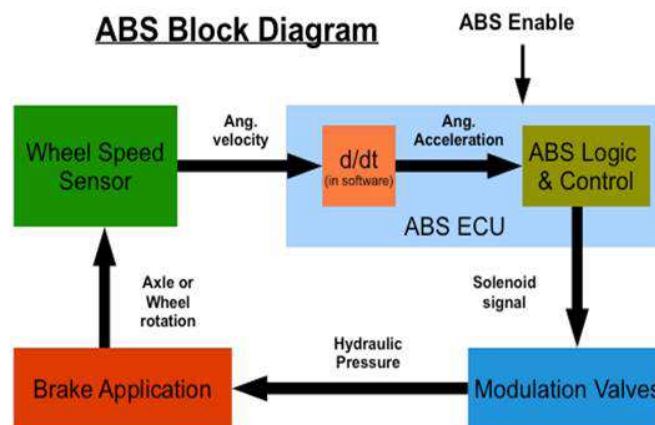


Figure 1.2: ABS Component Layout

1.2.2 Objective and Working of ABS

The objective of an ABS is to reduce the ideal stopping distance during sudden braking and provide better steer ability by avoiding skidding of a vehicle, also to maintain stability of the vehicle by controlling longitudinal slip in an operational range.

During normal braking, driver controls the brake pedal but when severe braking occurs, the peak brake pressure is detected by sensors, and from there ABS takes over. ECU utilizes a feedback system that responds to wheel slip and deceleration to modulate the brake pressure through booster assembly to reduce the wheel slip for optimal braking performance, and thus preventing the controlled wheel from fully locking.

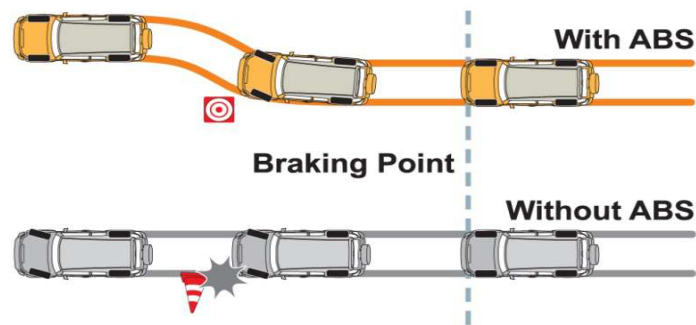


Figure 1.3: Working of ABS

ABS generally offers driver advanced vehicle control in surfaces with low coefficient of friction, such as muddy and wet roads. ABS generally minimize the stopping distance in slippery and dry surface, conversely on loose surface like gravel or snow covered pavement, ABS can significantly increase braking distance, although still improving vehicle control.

1.3 Traction Control System

Traction control System (TCS) is part of Electronic stability control (ESC). The general function of TCS is to control the sparking sequence, fuel supply and yaw in a vehicle when the vehicle loses traction during high speed, cornering and low speed acceleration. In 1994, Turbo supra was the first vehicle to use traction control system commercially.

1.3.1 Components of TCS

Major components of traction control system are same as Anti-locking braking with few additional systems in the engine bay.

- Solenoid engine valve controls
- Control valves in Fuel pump
- Booster and master cylinder assembly
- Wheel sensor
- Hydraulic control Modulator (6 solenoids)
- Electronic control unit (ECU)

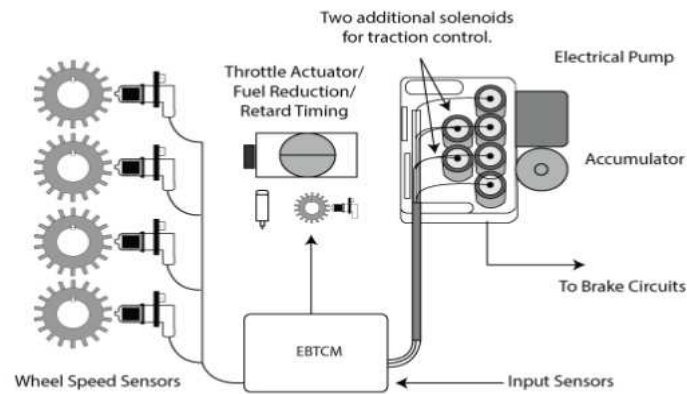


Figure 1.4: Components of TCS

1.3.2 Objective and Working of TCS

Seasonal changes and variable temperatures often take a hard toll on road conditions. Traction control can give stability and control in roads with low friction, and helps in sudden acceleration without wheel spinning

Traction control system works in multiple ways to control the rotational speed of wheel to provide maximum traction. When the wheel sensors detect a wheel spin, it engages the fuel pump solenoid valves to reduce engine power and regain traction. The driver may experience a pulsation in the gas pedal similar to the brake pedal in ABS. Another method TCS utilizes is, a combination of engine power reduction and wheel braking to achieve required traction and vehicle stability.

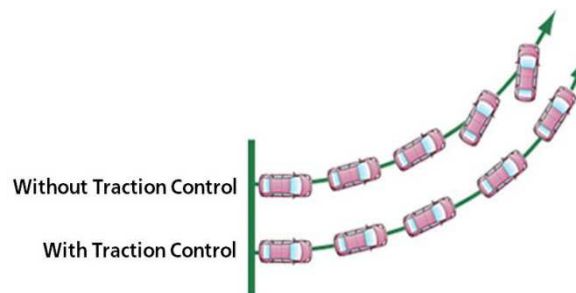


Figure 1.5: Working of TCS

Once the wheels have regained traction, the traction control systems returns to monitoring wheel speed and comparing the rotational speed of the vehicle's wheels.

1.4 Wheel Slip Ratio

Wheel slip is defined as the motion of wheel relative to the road. Slip occurs, when there is a difference between the theoretical and actual distance travelled by the wheel. When wheel slip occurs, actual distance travelled will be greater than the theoretical distance of the wheel.

Wheel slip is defined in terms of vehicle road speed and circumferential velocity of wheel.

$$\lambda = (v_f - v_w) / v_f$$

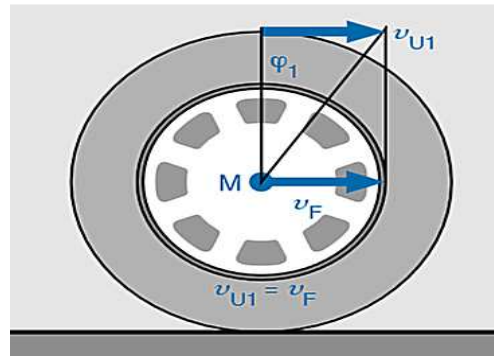


Figure 1.6: Braked Wheels

There are two types of Wheel Slip

- Longitudinal slip (Straight-line braking)
- Lateral slip (Cornering)

Longitudinal slip occurs due to the torque created by the engine or by applying brakes to accelerate or decelerate the car. In this project, only longitudinal slip will be accounted for, as straight line braking maneuver is applied to create slip on different road conditions.

1.5 Road Coefficient of Friction

The resistance offered by various possible materials between wheel and road surface when the wheel is free rolling on, it is called as coefficient of friction. Basically, it's the frictional properties of various materials, on which a wheel travels. When the brake is applied, a braking force is generated between the tire and the road, which is proportional to the braking force applied. Thus, it is a measure of the braking force that can be transmitted.

Co-Efficient of friction is defined as the ratio of the braking force and the vertical tire force, $\mu = F_b / F_v$

The coefficient of friction mainly depends on these factors

- Condition of tires
- Weather conditions
- Nature of road surface
- Vehicles road speed

Actual effectiveness of the braking torque is determined by the coefficient of friction. The Adhesion between the road and the wheel determines the wheels ability to transmit force. The ABS (Antilock Braking System) and TCS (Traction Control System) safety systems utilize the available adhesion to its maximum potential.

General values of Coefficient of friction under various speeds on different road conditions:

Table 1.1: CoF under Different Speeds

Vehicle Speed	Dry Road	Wet Road	Mud	Ice
50 Kmph	0.1	0.5	0.4	0.1
90Kmph	0.91	0.2	0.1	0.05
130Kmph	0.84	0.15	0.08	0

2. EXPERIMENTAL SET-UP

The main idea is to setup a system, which imitates the interaction between vehicle tire and road surface by simplifying it into individual components. The major components involved are wheel, road surface and vehicle road.

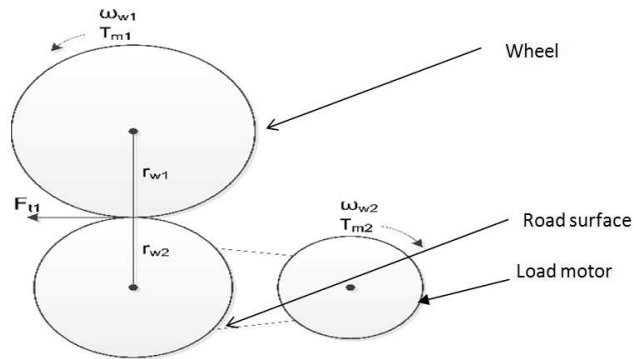


Figure 2.1: Setup to Imitate Road Wheel Interactions

The above figure shows a simplified setup of the tire road interactions. The r_1 represents the wheel, r_2 the road surface and r_3 the load component. In this setup, a wheel is placed above a roller attached to load control motor via chain link. The load motor will be used to control the slip and to rotate the roller to imitate a moving road surface.

Based on this, a system was setup using a wheel, load control motor and roller which will act as road surface in fabricated cage. The below shown figure is the computer design of the setup.

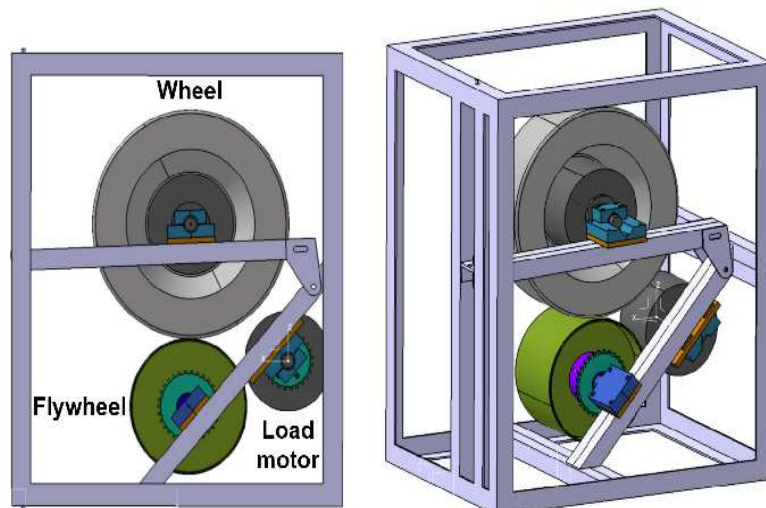


Figure 2.2: Setup Design



Figure 2.3: Actual Experimental Setup

3. RESULTS AND DISCUSSIONS

3.1 Rough Pavement

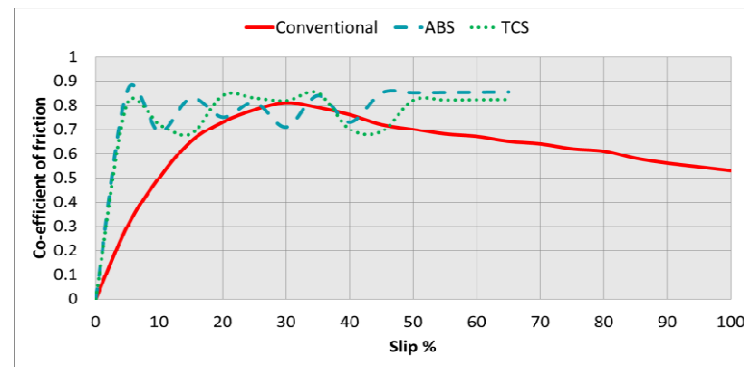


Figure 3.1: Comparison of Conventional, ABS and TCS on Rough Surface

In rough pavement, the coefficient of friction is maximum (i.e. 0.8-0.9), and 100% wheels lock occurs in conventional braking, and the steering control is lost. Whereas in ABS and TCS, complete wheel lock is prevented by controlling engine torque and pulsating brake pressure. Although ABS prevents complete wheel lock, TCS has been slightly more effective, as it includes more variables compared to ABS such as engine torque, vehicle speed.

3.2 Smooth Pavement

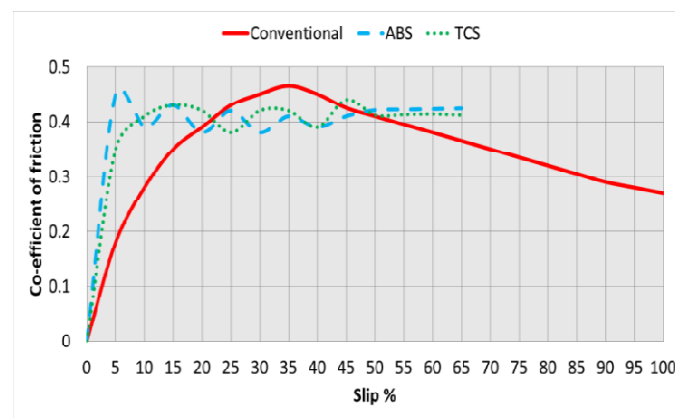


Figure 3.2: Comparison of Conventional, ABS and TCS on Smooth Surface

In smooth pavement, the Coefficient of friction is in the range of 0.35-0.45. The Cof plot is very much similar to that of rough pavement. Here also, wheel lock occurs only in Conventional braking and traction is regained in other two braking methods.

3.3 Gravel Surface

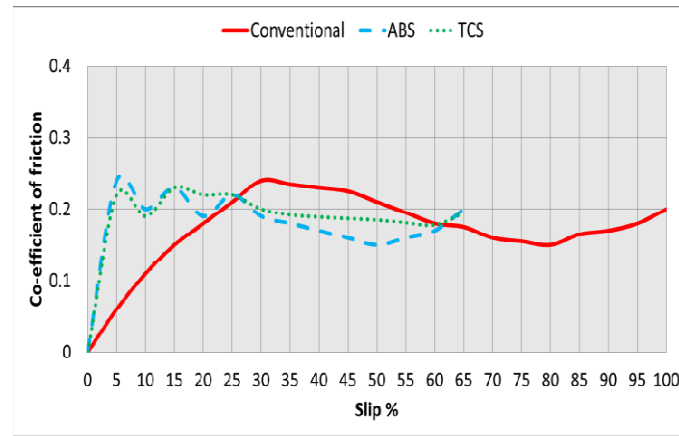


Figure 3.3: Comparison of Conventional, ABS and TCS on Gravel

Gravelled and mud surface has more loose elements, thereby reducing coefficient of friction in the range of 0.1-0.3. Conventional braking on gravelled road surface leads to accumulation of material in front of wheel, also called piling, leading to wheel spin and tipping of vehicle. ABS controls the brake pressure and prevents wheel lock, whereas TCS cuts power to the spinning wheel and diverts the engine torque to the wheels with traction.

3.4 Mud Surface

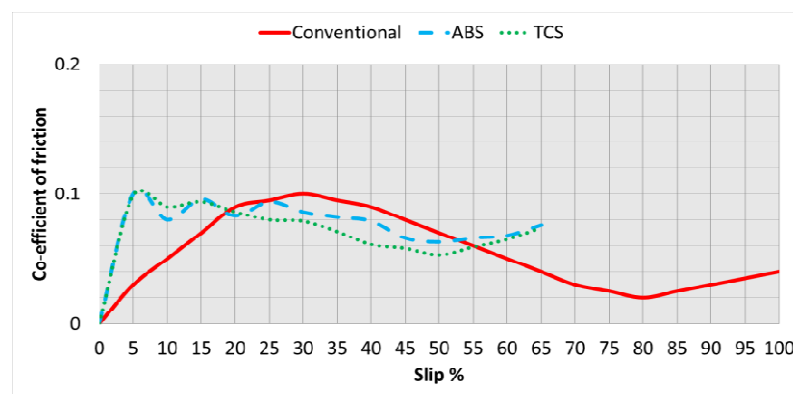


Figure 3.4: Comparison of Conventional, ABS and TCS on Mud

Oily and ice surfaces has the lowest coefficient of friction i.e. below 0.1. Conventional braking results in sliding uncontrollably in all directions. ABS provides some traction in low speeds, but results are same as conventional braking at high speeds. Purpose of TCS is to increase traction, but as traction is negligible, the functionality of TCS is not utilized in ice and oily surface.

3.5 Ice Surface

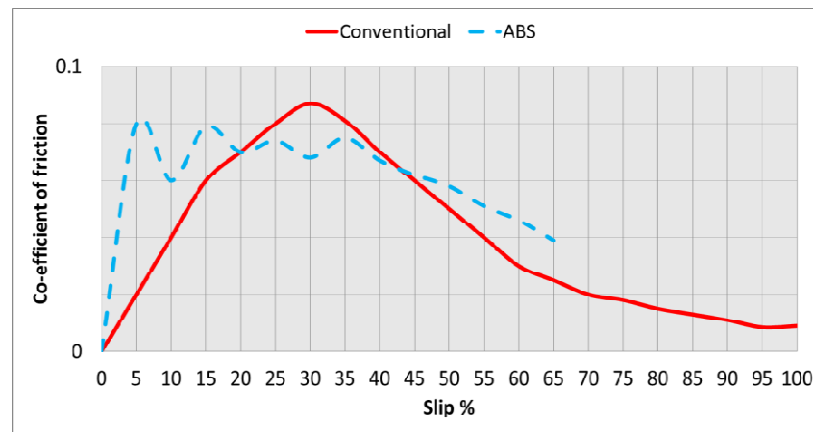


Figure 3.5: Comparison of Conventional, ABS and TCS on Ice

3.6 Comparison of Slip Occurring at 65% in Different Road Surfaces under Various Control Methods

Table 3.6: Comparison of Slip at 65%

Methods	Slip at 65%			
	Rough	Smooth	Gravel	Mud
Conventional Braking	0.67	0.38	0.18	0.05
ABS	0.854	0.424	0.2	0.076
TCS	0.824	0.412	0.195	0.074

4. CONCLUSIONS

The effects of vehicle speed and type of road surface on tire longitudinal slip and on brake stopping distance are investigated. The number of wheel revolutions to travel this distance at each speed and on both roads was measured using a wheel revolution counter, specially developed for this purpose. This data was used to calculate the tire longitudinal slip at each speed and on both roads. Effect of using Anti-lock Brake System (ABS) on the brake stopping distances was also investigated.

Test results indicate that the tire longitudinal slip and brake stopping distance are both directly proportional to vehicle speed, and they are significantly higher on gravel road than they are on rough pavement.

The increase of vehicle speed resulted in a massive increase in tire slip by approximately 3.6 times. For the same increase in vehicle speed, the increase in stopping distance is even more significant; it increased by approximately 15 and 18 times on asphalt and earth roads, respectively.

The effect of type of road surface is indicated by the fact that at 100 km/h, the tire longitudinal slip and the brake stopping distance on earth road are higher than those on asphalt by 54% and 29%, respectively.

Finally, test results indicate that the use of ABS has adverse effects on the brake stopping distance. On rough pavement the stopping distance increased by 6.7%, and on smooth pavement 11.3%, as a result of using ABS.

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